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DETAILED SURVEY OF 60-Hz MAGNETIC FIELDS IN SCHOOLS

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Surveys have been made of power frequency magnetic fields in two schools. Measured field levels clustered around the 0.06-0.125 μT (0.6-1.25 mG) range, a factor of two less than levels in homes. Classroom fields exhibited low-level fields, typically on the order of 0.05 μT (0.5 mG). While a transmission line near one school raised ambient levels slightly, fields were due mainly to local sources: building wiring as well as distribution panels. In one school, the major field source is a site transformer. However, the highest fields outside the transformer room, 0.3 μT (3 mG), are found right next to the room, and decay rapidly with distance from the transformer.

1. Introduction

Public concerns about the possible health effects of 60-Hz magnetic fields, especially in children, have prompted detailed investigations of field sources and their ambient levels, primarily in residential situations. While early studies have used characteristics of the electrical distribution system, such as transmission or distribution wire type and location, as surrogates for the magnetic field, more recent studies have used direct field measurements. Over time a large body of data dealing with such measurements of magnetic fields in houses has been collected [Mader et al 1990, 1991]. On the other hand, the corresponding database for schools is sparser [Harvey 1987, Bruyn et al 1990]. Since children spend a significant amount of time in schools, however, there is a need to identify and characterize magnetic field sources in this environment.

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This report aims to fulfill some of this need. It presents detailed spatial and temporal surveys of two representative schools in the Toronto area, one a smaller, older school with a relatively simpler electrical network, and the other a newer, larger facility with a more complex electrical system. In addition, the latter school is in relatively close proximity to a transmission line corridor. This survey identifies the significant field sources in these schools, and compares and contrasts the consequent magnetic field environments. This work is complementary to long-term dosimetric studies of children [Donnelly and Agnew 1991] and to magnetic field measurements in houses, and helps provide a more complete picture of the field environment encountered in our daily lives.

2. Magnetic Fields Sources in Schools

The 60-Hz magnetic fields in and around any building, such as a school, are a result of power-frequency current flow in conductors in the vicinity of the building. Magnetic field sources inside the building include the internal building wiring, plumbing, and electrical equipment such as transformers, electrical heaters, lighting, appliances, office equipment and personal computers. Other sources include the electrical distribution system, including high-voltage transmission lines and distribution lines, and any other utility network through which net currents may be flowing. The latter include municipal water mains, gas lines and telecommunications systems.

Previous work on magnetic fields in single-family homes [Mader et al 1990, 1991] has shown that the fields at any point in a house may be calculated reliably from only a few measurements. First, the field from sources external to the house is assumed to be spatially uniform. This field, the ambient magnetic field, may then be measured with a single one-axis coil at a location in the house chosen so as to avoid other magnetic field sources. Secondly, one considers the magnetic field due to net currents in the residential service drop, grounding wire and plumbing. This latter source is usually due to the practice of connecting the neutral of the service drop to metal water pipes for grounding purposes. The magnetic field due to these grounding currents may then be added vectorially to the ambient magnetic field to give the total field in the residence at any location or time.

In essence, the total magnetic field in a house may be obtained from three measurements: (a) the ambient magnetic field (and its phase relative to the grounding current), (b) the location of the ground circuit conductors, and (c) the net current on the grounding circuit. In principle this can be extended to any type of building. In practice, however, schools and other larger buildings present several complications.

First, the ambient magnetic field in a school is not necessarily spatially uniform, and may not have only a vertical component. This is primarily because of the size of the school, and the situation may be modified even further if a transmission line is located near the building.

Second, the number of possible ground circuit conduction paths in a school may be much larger than in a house: studies have indicated that grounding current may flow through steel building

frameworks, metal air ducting, conductive joists in the floor or roof, in addition to already-identified paths such as telecommunications and gas lines [Johnson 1991]. Moreover, the layout of these paths is usually difficult to ascertain: paths are embedded in the building, buried, or hidden in the ceilings, and over time the building wiring may be changed considerably. The scale of the building then makes current paths nearly impossible to trace.

Third, while in houses a single grounding current path normally suffices for source characterization purposes, schools and other large buildings will usually have multiple grounding paths due to interconnections of various conductive elements. This complicates any deterministic theoretical analysis.

Fourth, while appliances and electrical equipment may be neglected in a house environment, this may not be necessarily true in schools and other buildings. Often schools have their own individual step-down transformers located on the school grounds, and they may also have large heating and cooling units, which may affect the magnetic field environment in a school [Mader and Peralta 1991].

The accurate calculation of the total magnetic field at any point in a school can thus be an extremely complex task. The scale of the situation alone makes field surveys the most reliable means of characterizing the magnetic environment in schools and similar buildings.

3. Survey Sites

The Etobicoke Board of Education was contacted for help in identifying the schools and in securing the cooperation of school staff for the survey. Since the magnetic field measurements were thought to be possibly affected by the complexity (size) and the age of the associated electrical network, it was thought that we could focus on one large new school and one smaller older school. After consultation with the Board, the following sites were chosen: Sunnylea Public School (35 Glenroy Avenue) and Albion Heights Public School (45 Lynmount Road). Simplified floor and site plans of the selected schools are shown in Figures 1-2. More detailed site plans, consisting of approximately 50 scaled blueprint drawings of the physical layout and electrical schematics for the schools, were also obtained from the Board to supplement these simplified plans.

3a. Sunnylea Public School

Sunnylea Public School is a school with a relatively older structure, originally designed and built in 1948; since then it has undergone several renovations. The school is medium-sized. The first floor contains 12 classrooms, a kindergarten, a library, a general purpose room (gymnasium/assembly), and several staff and utility rooms and offices. The basement houses the boiler and mechanical rooms, as well as an audiovisual room, an art classroom, and student washrooms. Gas heating is used in this school. The school (first floor) covers roughly 2500 m^2

(3000 sq. yds.) on a site approximately 15470 m^2 (18500 sq. yds.) in area, which includes a paved play area and a football field.

Connection to the distribution system is via a service drop at the northwest corner of the building. A number of distribution panels are located along the main corridor of each wing in the school. There are no transmission lines in the immediate vicinity of the school. Ballast magnetic fields from the fluorescent lighting predominantly used was not expected to add significantly to the field, as their average distance from standard working areas is large enough so that the associated fields are essentially zero.

3b. Albion Heights Public School

Albion Heights Public School is a relatively new facility, originally designed and constructed in 1970. The school is quite large, more than twice the size of Sunnylea P.S. in floor area. The central first floor is dominated by a general purpose room ringed by changing rooms, storage areas, washrooms, staff offices, and a library. The first floor north wing houses 4 classrooms and 3 seminar rooms. The south wing is a large open concept room which utilizes partitions to subdivide as many as 6 kindergarten classrooms. The school transformer room and electrical rooms are also located on the first floor, near the entry to the school. On the second floor are located 10 additional classrooms, a general purpose activities area, a computer classroom, another large open concept area partitioned into four classrooms, and several teacher workrooms, storage offices, and washrooms. The school's first floor covers roughly 3345 m^2 (4000 sq. yds.) and second floor 1670 m^2 (2000 sq. yds.) on a site approximately 20070 m^2 (24000 sq. yds.) in area, which includes a soccer and baseball field, a paved play area, and paved parking for 58 cars.

A transmission line located some 500 meters west is visible from the school. The school's on-site transformer is fed via hydro lines running underneath the parking lot, in conjunction with telephone lines. Electrical lines through risers and in the first floor ceiling connect the central transformer to distribution panels throughout the building. The school is electrically heated; it is equipped with six rooftop heating units and air conditioners, with 70-110 kW (approximately 10-15 h.p.) supply fans and 750 W (1 h.p.) exhaust fans. These are located primarily in mechanical rooms on the perimeter roof, a few of which are in close proximity to second floor classrooms. In contrast to the situation with Sunnylea P.S., magnetic fields associated with fluorescent lighting for first floor classes in Albion Heights P.S. might possibly contribute to second floor fields, depending on the proximity.

4. Preliminary Survey

A hand-held magnetic field meter (Model 42A-1, Monitor Industries, Boulder, CO, U.S.A.) was used in a preliminary survey of both schools to identify any significant magnetic field sources. Rod-mounted coils were also used to probe places difficult to reach, such as ceiling fixtures. As expected, elevated power-frequency magnetic fields were found close to transformers (in Albion

Heights P.S.) and distribution panels. At heights of 1-2 m from the ground, no significant fields were found from fluorescent light ballasts in either school. Elevated fields were also found in proximity to service drops and underground hydro cables. Ambient fields in student-use areas such as classrooms, general purpose rooms, libraries, corridors, fields and playgrounds, were found in the preliminary survey to have fields generally in the range from 0.05-0.1 μT (0.5-1 mG). This was found in both schools, despite the existence of a neighbouring transmission line in the case of Albion Heights P.S. In comparison, most residential fields are in the range of 0.1-0.4 μT (1-4 mG).

Clamp-on ammeters were also used for the purpose of measuring ground currents through grounding conductors. Although these proved useful in the residential situation, their utility was limited in the schools surveyed for two reasons. First, as observed above, conductors were found to be more inaccessible than in the residential setting; they were usually behind walls, buried or in ceilings and roofs. Second, conductors that were accessible were not always conveniently sized for conventional clamp-on ammeters; almost invariably their cable/housing diameters were much larger than the clamp. In the conductors that were both accessible and on which clamp ammeters were usable, grounding currents were found to be on the order of 1 A, similar to residential ground currents. However, current readings are by no means conclusive in the complex electrical network a school presents. In one case in Sunnylea P.S., it was noted that an initial reading found no current, but movement of a nearby wire produced a reading of nearly 1 A! It was taken that the connection of the grounding wire to the water main was faulty (For safety reasons, this was brought to the attention of the school caretaker.) Given these circumstances, theoretical reconstruction of the magnetic field from the currents and geometry of the grounding conductors, while tractable in single-family houses, was deemed unrealistic in the case of schools. The detailed survey described below thus constitutes directly measured magnetic fields.

5. Measurement Procedure for the Detailed Survey

For the detailed survey, magnetic fields were measured using a battery-powered programmable Emdex-C gaussmeter (Electric Field Measurements Co., W. Stockridge, MA, U.S.A.). The Emdex-C has three mutually perpendicular pick-up coils and vectorially computes the total field magnitude. Approximately 1400 such measurements may be made and stored in the Emdex-C. These measurements may be downloaded into a computer for later reference.

Two modes of operation were used. In the first mode, used for the spatial surveys, the Emdex-C was mounted on a wheeled platform 1 m above ground level; a mechanical switch attached to the wheel enabled measurements to be taken at programmable distance intervals. In our measurements this interval was programmed as 2 m.

In the second mode, used for the 24-hour surveys, the Emdex-C could be programmed to take magnetic field readings at predetermined time intervals. The detailed spatial and 24-hour surveys

were made on Sunnylea P.S. in April 1991 and at Albion Heights P.S. over the period from April-May 1991.

In general, the measurement protocol was as follows: For corridors, survey lines were chosen on either side of the corridor at a fixed distance from either wall, and the magnetic field was measured every 2 m along the survey lines. In classrooms, three to five survey lines were chosen parallel to the outside corridor; the magnetic field was measured every 2 m along the survey lines. For the exterior surveys, survey lines were chosen to cover the school property; the magnetic field was again measured every 2 m on each of the survey lines. Where the preliminary field survey indicated a notable magnetic field source (conductor), either interior or exterior to the school, detailed measurements were made at closer points, to obtain a better field profile.

Programming of the Emdex-C and storage of the acquired data was accomplished via a portable computer (Sharp model PC-7220). Because of the size of the database, downloading of the data was done after every room/corridor survey. A custom program enabled the data to be viewed and checked for consistency at this stage. After collection, the data obtained was translated from binary to ASCII, and then analyzed and plotted using commercial GRAFTOOL graphic software as well as other custom programs. This procedure enabled interpolation between measured data points to provide for a regular grid pattern, as well as visualization by three-dimensional or contour-plot representation.

6. Survey Results

The detailed survey results are summarized in Figures 3-5 for Sunnylea P.S. and in Figures 6-8 for Albion Heights P.S. We discuss each set of results in turn and then compare and contrast the respective field environments with a mind to generalize the results.

6a. Sunnylea Public School

Figure 3a shows a three-dimensional map of the magnetic field levels at ground level (first floor of the school building and surrounding school grounds) at Sunnylea P.S. Overall the magnetic fields appear to be quite uniform, except for a few peaks rising to a maximum of 0.4 μT (4 mG) around the perimeter of the school. We can characterize the fields by referring to Figure 3b, which shows a contour map of the ground level magnetic fields at Sunnylea P.S. For reference, the actual school building is outlined in dark lines on the same map. Lines defining the 0.1 μT (1 mG) contours are also shown.

From this we can see that in general, the magnetic fields in the school are fairly low-level, at around 0.1 μT (1 mG) and lower. The regions where the magnetic field is slightly elevated can be seen identified by contour lines ranging from 0.2-0.4 μT (2-4 mG). We should note that all of these peaks are located on sidewalks opposite the school, near single-family homes. Opposite

the western side of the school, elevated fields track a distribution line which runs in the north-south direction. The magnetic field due to this distribution line decays very rapidly, and contributes a negligible amount to the field levels on school grounds. Three magnetic field peaks may be identified along this line, arranged remarkably linearly, with a regular spacing of about 45 m. These distances correspond well to the service drops to homes in this area. The same is probably true for the peak opposite the northeastern corner of the school. Another peak, near the northwestern corner of the school, may also be associated with the service drop to the school, which is located at that position. It is noteworthy that the fall-off of these field maxima with distance is consistent with the behaviour of fields due to linear currents (transmission/distribution line fields). The decay rate is approximately $1/d^2$, where d is the distance from the field source; this dependence indicates that this field is due to load rather than net currents, which would show a 1/d dependence.

Figure 3c shows a three-dimensional map of the ground level magnetic fields at Sunnylea P.S., with special focus on the first floor of the school building, and Figure 3d shows the corresponding contour map. The three-dimensional map exhibits some peaks, but these are only at approximately 0.1 μT (1 mG). The contour map shows us that in general these peaks occur in the corridors, which run down the middle of each wing of the school, rather than inside the classrooms. Although a few of the peaks are associated with distribution panels, some panels (for example, one near 70 m N, 12 m W) do not even register 0.05 μT (0.5 mG). The fields everywhere else within the school are below 0.5 μT (5 mG).

Figure 3e and 3f show a three-dimensional and a contour map, respectively, of the magnetic field levels at the basement level at Sunnylea P.S. The fields in the basement are similarly very low, at or below 0.05 μT (0.5 mG) except for one reading of 0.1 μT (1 mG) at the southwest edge of the art classroom. This may be indicative of the proximity of plumbing or pump motors near the boiler room which may be serving as a current-carrying source. Nevertheless, in general the magnetic fields in the basement remain very low-level.

Figure 4a shows a histogram of the spatial magnetic field levels for the entire school building at Sunnylea P.S. From this graph we see that in general the magnetic field levels within the building cluster around the 0.08 μT (0.8 mG) value; some counts were taken in the 0.06 μT (0.6 mG) and 0.1 μT (1 mG) bins, but the counts drop rapidly thereafter. Figure 4b shows a similar magnetic field level histogram, including field levels in both the school building and the surrounding school grounds. The general field levels in this case cluster around the 0.06 μT (0.6 mG) region. There is a longer high field tail, and a small rise in the counts for fields around the 0.28 μT (2.8 mG) level; this latter is due to fields from service drops to homes surrounding the school.

Figure 5 shows the time variation of the magnetic field as measured in the custodial office on the first floor, over 24 hours at Sunnylea P.S. The field here is typical of that found in the classroom. The mean field here is around 0.07 μT (0.7 mG), corresponding well with the maximum count value in the building histogram, with a variation ranging from 0.03-0.1 μT (0.3-1 mG). These extreme values are well within the range described by the building histogram, and

supports the notion that the general field characteristics described above are not wildly variant over time.

6b. Albion Heights Public School

Figure 6a shows a three-dimensional map of the magnetic field levels at ground level (first floor of the school building and surrounding school grounds) at Albion Heights P.S. As in Sunnylea P.S., the magnetic field profile is quite uniform over the entire school area, except for one notable spike. Unlike the more gradual humps in the Sunnylea P.S. data, the magnetic field maxima here are very sharp. This is indicative of dipole fields, magnetic fields due to appliances or electrical equipment, rather than linear current fields. The peaks are also considerably higher than in Sunnylea, reaching approximately 1.35 μT (13.5 mG). Referring to the layout of the school in Figure 2, as well as the contour map in Figure 6b, we see that the two large peaks occur in the region of the transformer and electrical rooms of the school, validating the conclusion that these are appliance/equipment magnetic fields.

Despite the large fields near the on-site transformers, the fact that they are dipole-type fields means they decrease very rapidly with distance from the source with a decay rate of $1/d^3$, where d is the distance between the source and the point where the field is measured. Thus, it is not surprising that in the rest of the school, the fields are typically 0.1 μT (1 mG) or lower, similar to the case in Sunnylea P.S.

Now, in Sunnylea P.S., it was indicated that the small peaks in the field profile were associated with distribution panels along the corridors of the school. The situation is different in Albion Heights P.S. in that the 0.1 μT (1 mG) contour lines do not show any relationship with the location of either distribution panels, fluorescent lighting, or any other electrical equipment. The source for this field, however, may be identified with reference to Figures 6c and 6d, which show, respectively, a three-dimensional map and a contour map of the ground level magnetic fields in more detail, focusing on the first floor of the school building. Starting from the north side of the school there is a very gradual rise in the ambient field level as we go south. In the detailed contour map, the 0.1 μT (1 mG) field contours also point to a general increase in the ambient field as we go toward the lower right hand side of the school. These two observations, in fact, are consistent with the fact that there is a transmission line corridor located not far from the school, in that precise direction. As with linear current fields, the field decrease is gradual, but by the time the field is measured at the school, the value has already dropped to its relatively low level of about 0.1 μT (1 mG).

The second floor level of Albion Heights P.S. exhibits the magnetic field profile shown in Figures 6e and 6f. The field is highly variable here, but there was no apparent correlation again with distribution panels, light fixtures, or even heating and cooling units. Instead, we surmise that they are due to the vector addition of fields due to currents in both the floor and ceiling of the second floor. It is notable that the fields on the second floor are on the whole lower than the

on the ground floor. A computer room is also located on the second floor, but fields in this room were no higher than anywhere else on the second floor.

Figure 7a shows a histogram of the spatial magnetic field levels for the entire school building at Albion Heights P.S. This gives us a value of about 0.125 μT (1.25 mG) in the school. Note that the appliance fields due to the on-site transformers do not contribute significantly to the ambient field, and there are extremely few counts in the higher ranges. In any case, children are not in general allowed within the transformer room or electrical rooms of the school, where electrical safety considerations apply. Including the playground in the histogram, as in Figure 7b, shifts the typical field encountered down slightly to 0.1 μT (1 mG).

Figure 8 shows the time variation of the magnetic field in the general office at Albion Heights P.S., over 24 hours. As expected, the field levels are quite stable, with a mean field of 0.12 μT (1.2 mG) and a variation from 0.09-0.145 μT (0.9-1.45 mG).

6c. Summary

In Canada, the mean value for magnetic fields in residences has been reported to be around 0.25 μT (2.5 mG) [Mader et al 1990]. In general, both the ambient interior and exterior fields found in the schools surveyed here are much lower. Histograms show that the predominant value of the magnetic field throughout the school grounds ranges from 0.06-0.125 μT (0.6-1.25 mG).

Although the interior and exterior magnetic fields at Albion Heights P.S. contain a small magnetic field component from the nearby transmission line, its field profile was quite similar to that of Sunnylea P.S. It appears that the interior magnetic fields are generally independent of whether the building is in the vicinity of a power line or not. Of course, closer proximity would elevate the ambient fields to a certain degree.

The interior magnetic fields in both schools is due primarily to local magnetic field sources in the schools, including building conductors as well as electrical equipment such as distribution panels. No significant fields were found due to either fluorescent lighting or heating/cooling units. It should be noted that measurements were done in spring, and it was possible to monitor on/off variations in the field near the heating/cooling units at Albion Heights P.S. However, these variations do not substantially affect classroom areas not in proximity to the equipment. Daily (24-hour) variations for a single location fall within the range of magnetic field variation throughout the school; however, the study has not looked for seasonal (annual) variations, which may affect the ambient fields.

Fields in classrooms and playgrounds, where students spend most of their time, are low-level in both schools, with typical fields on the order of 0.05 μT (0.5 mG) or less. Fields at the perimeter of the school property due to nearby transmission lines or service drops are higher, in the 0.1-0.2 μT (1-2 mG) range.

While the schools exhibited slightly elevated fields near distribution panels or hydro service drops, on the order of residential fields, the major difference between Sunnylea P.S. and Albion Heights P.S. appears to be the on-site transformers at the latter school. As expected, high magnetic fields were found near these transformers. These fields are not considered significant, however, because dipole fields, such as these transformer and distribution fields, decay extremely rapidly with distance, so that after two or three meters their effect is negligible. Furthermore, transformers and other similar electrical equipment are inaccessible to students and untrained personnel, because of electrical safety (shock) considerations. This equipment is, therefore, usually located far enough away from general areas so that their fields have decayed to much lower levels. In Albion Heights P.S., for example, the highest transformer field levels outside the transformer room are found right next to the walls of the room, and are only about 0.3 μT (3 mG).

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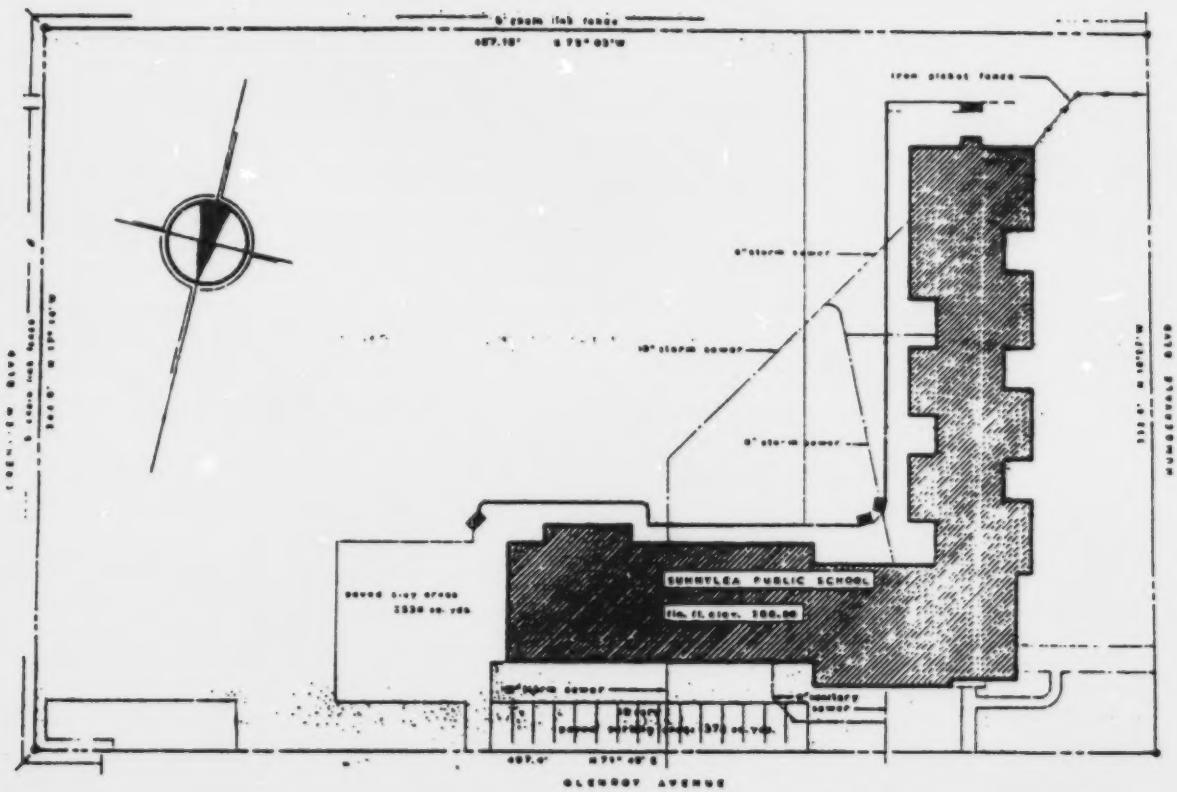

Figure 1a. Site layout, Sunnylea P.S.

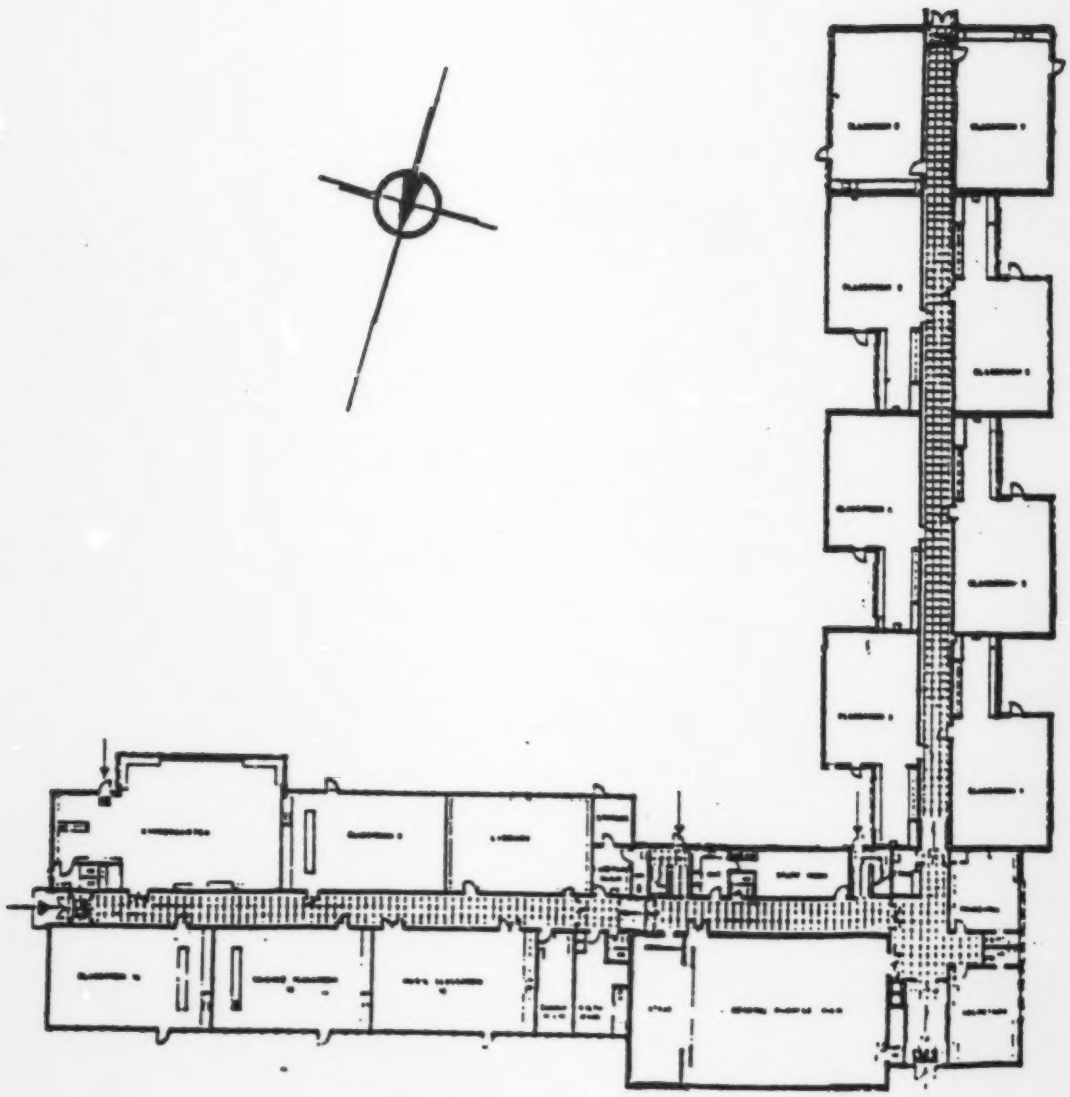

Figure 1b. Layout of first floor, Sunnylea P.S.

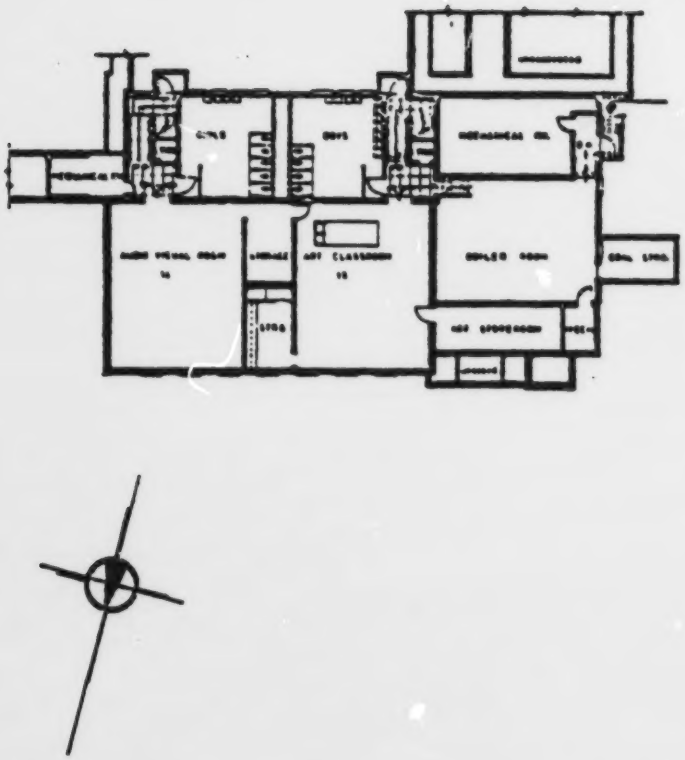

Figure 1c. Layout of basement, Sunnylea P.S.

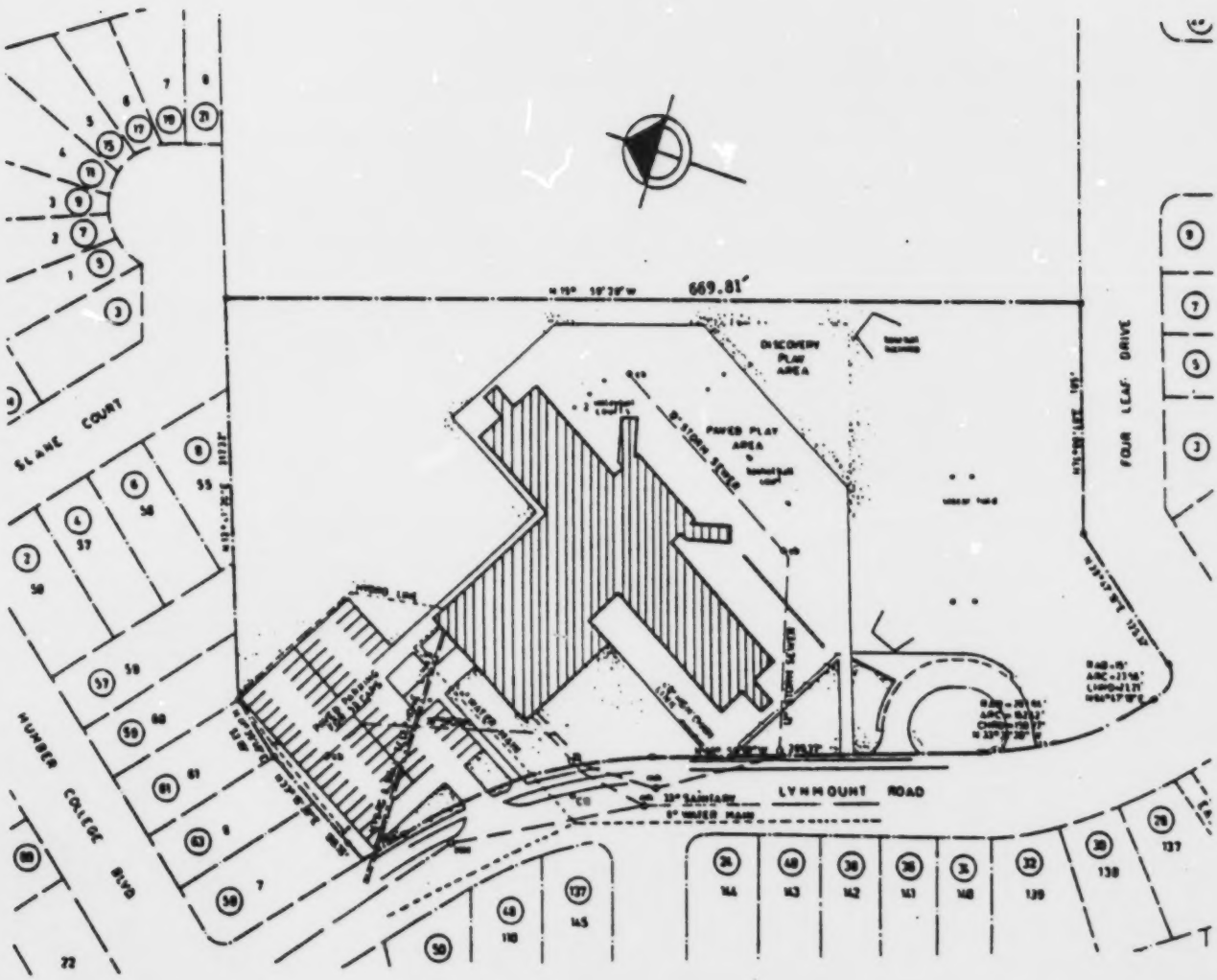

Figure 2a. Site layout, Albion Heights P.S.

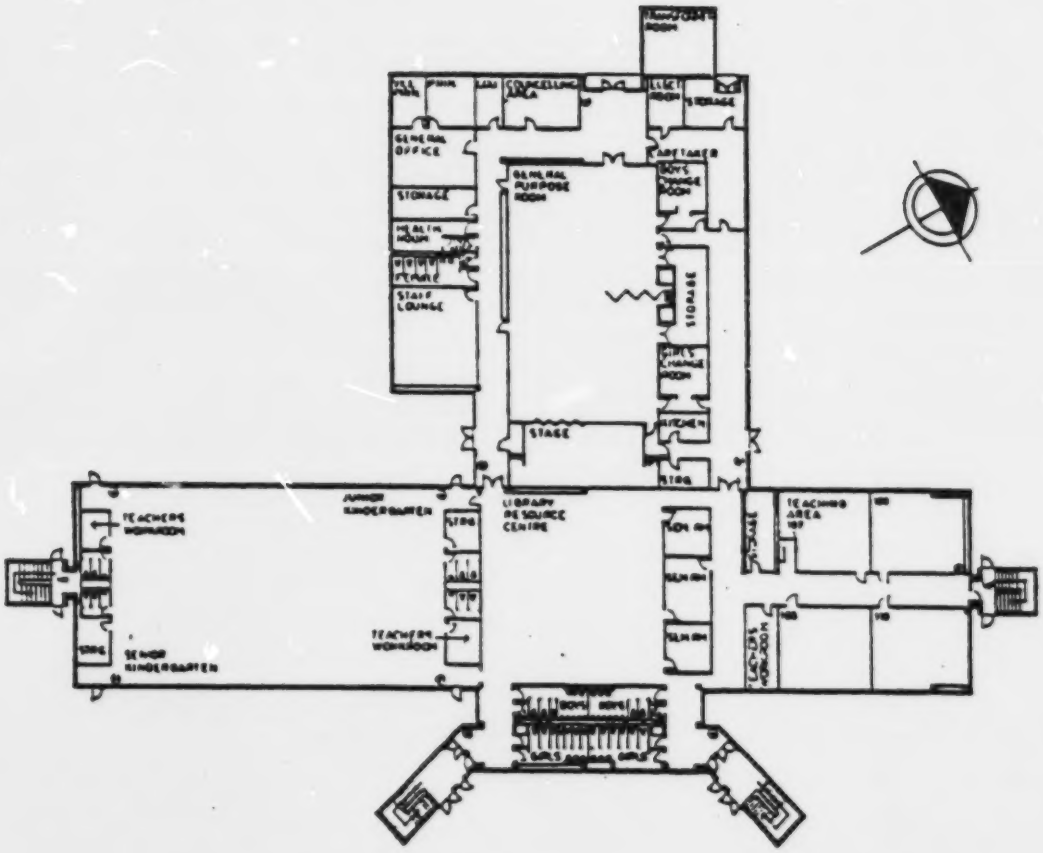

Figure 2b. Layout of first floor, Albion Heights P.S.

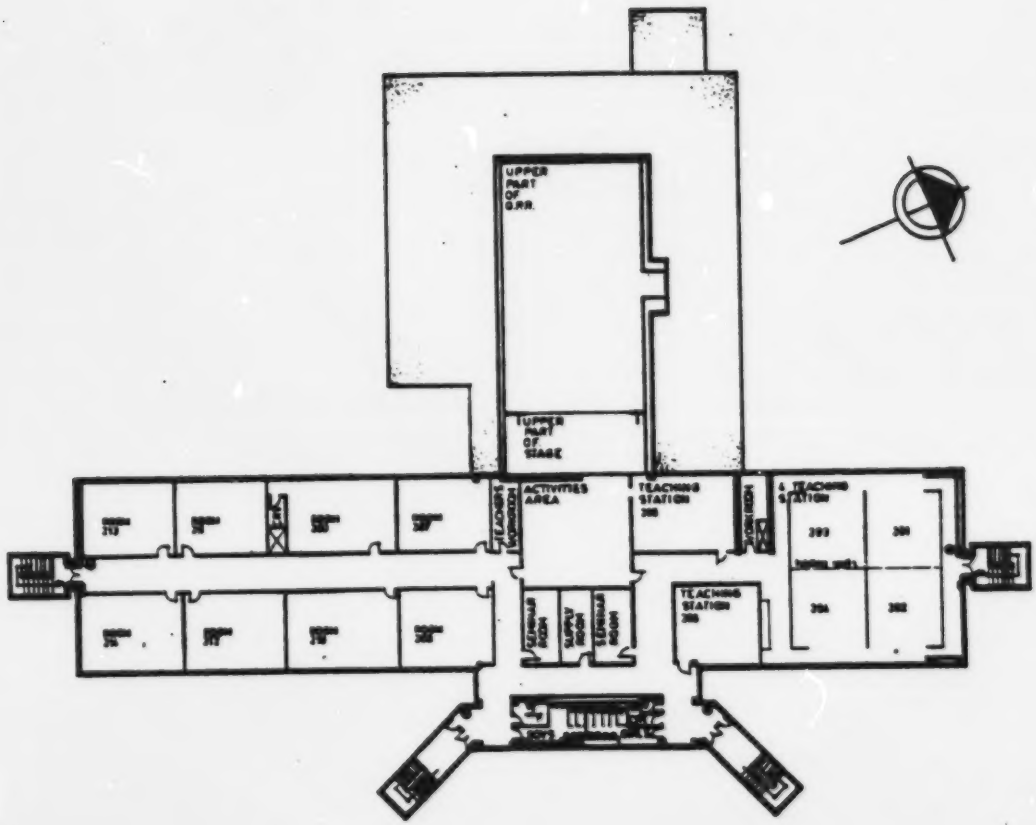

Figure 2c. Layout of second floor, Albion Heights P.S.

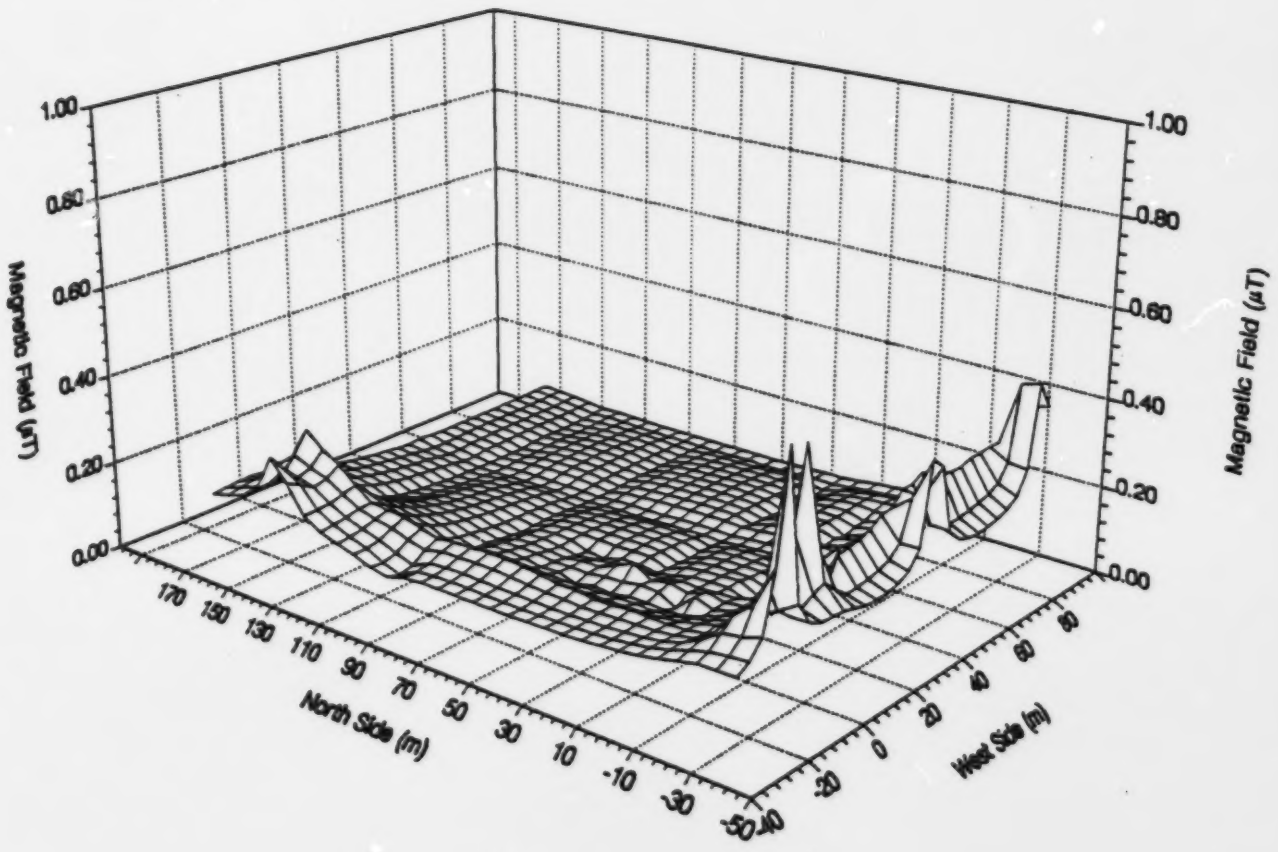

Figure 3a. Three-dimensional map of magnetic fields. First floor and surrounding school grounds, Sunnylea P.S.

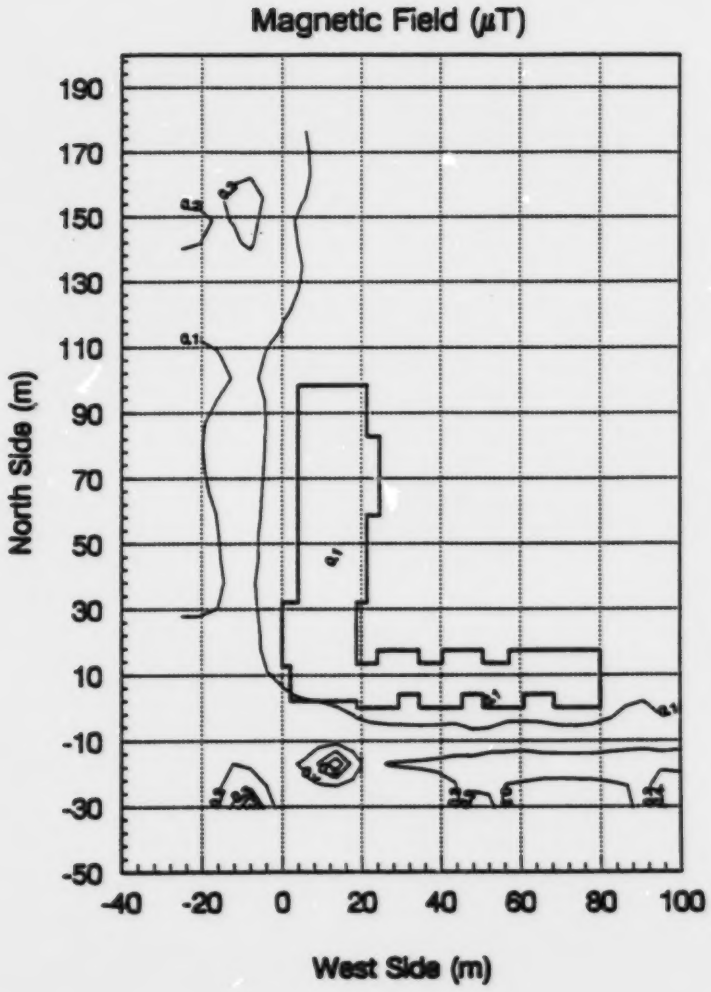

Figure 3b. Contour map of magnetic fields. First floor and surrounding school grounds, Sunnylea P.S.

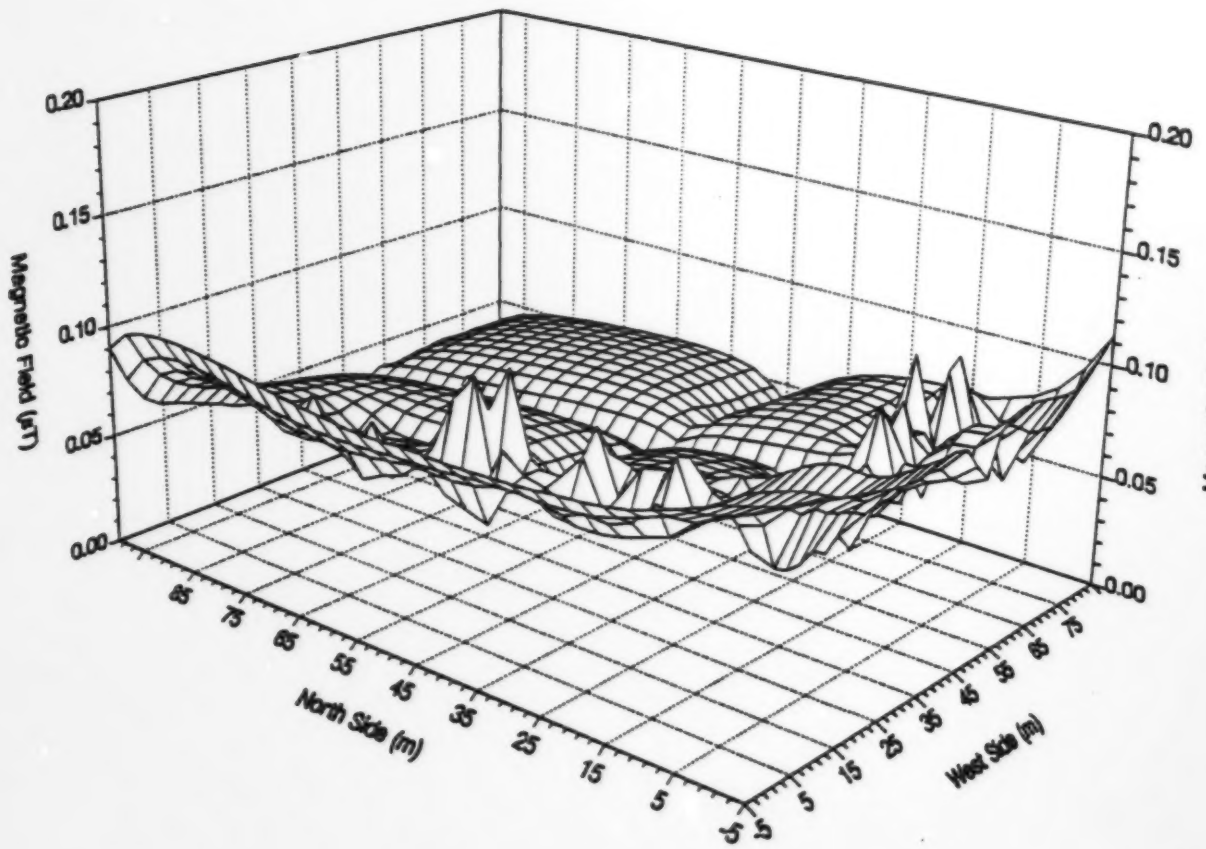

Figure 3c. Three-dimensional map of magnetic fields. First floor, Sunnylea P.S.

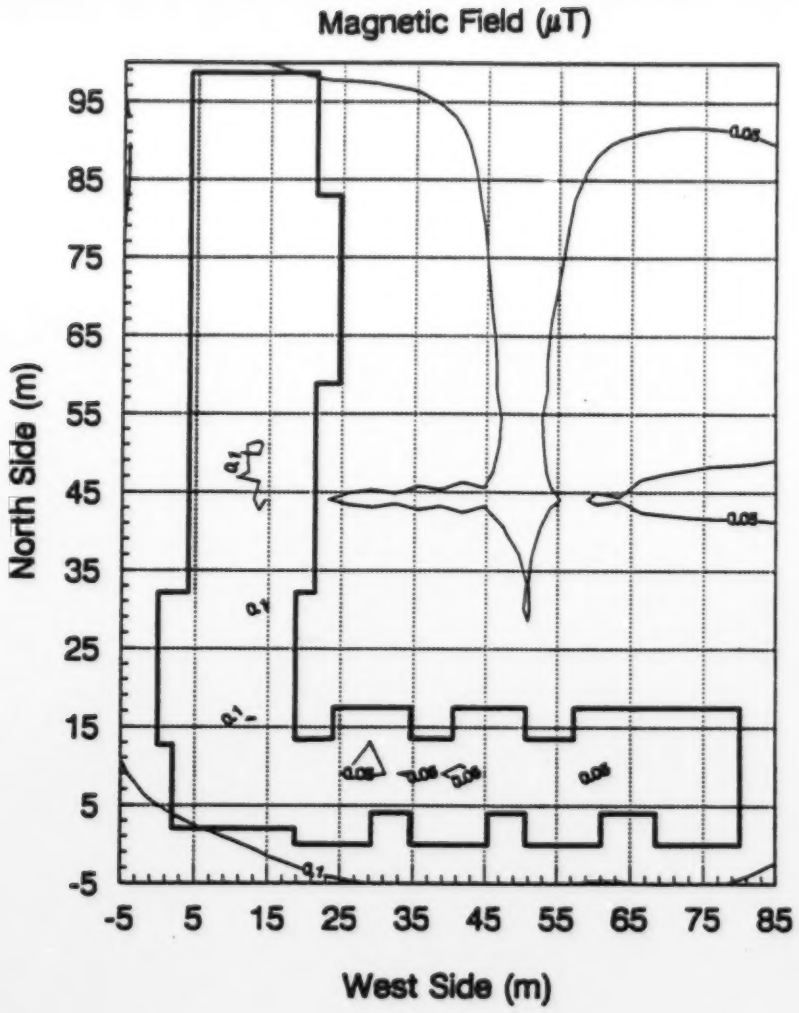

Figure 3d. Contour map of magnetic fields. First floor, Sunnylea.

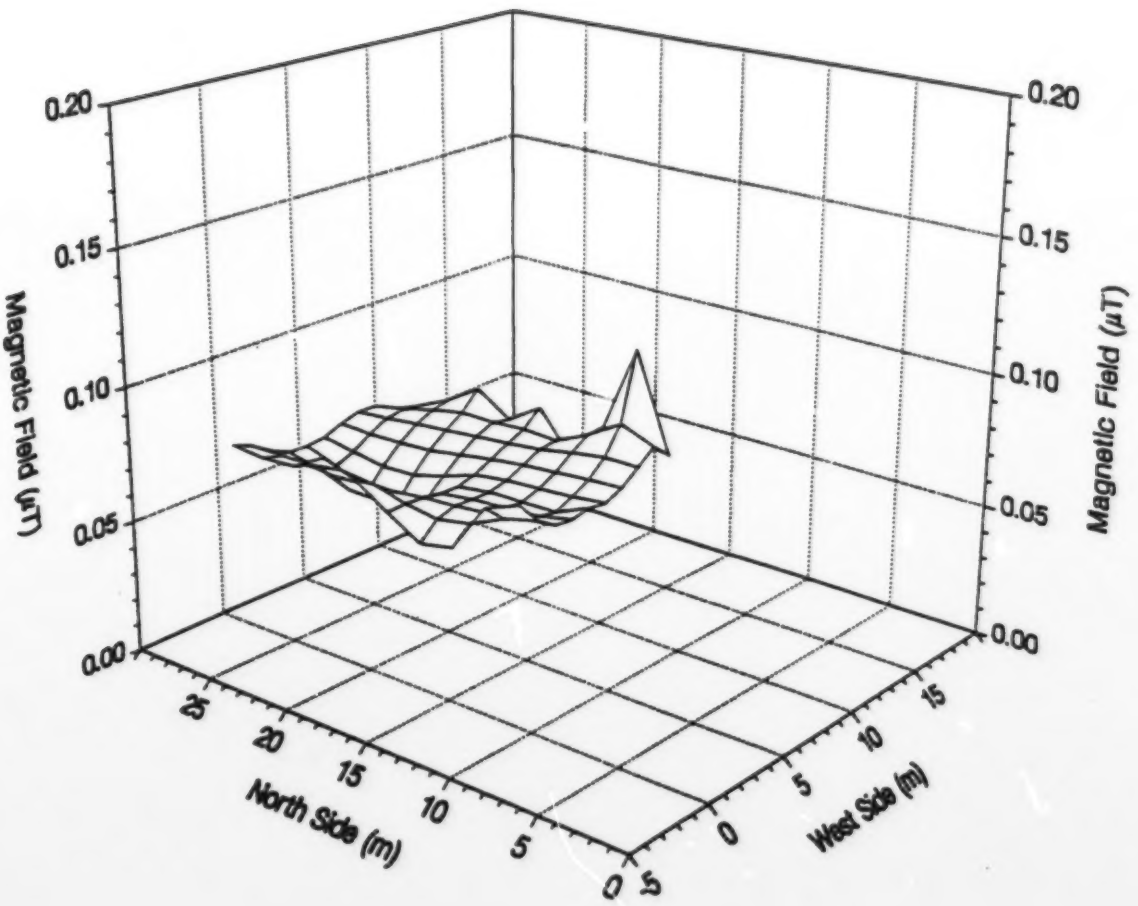

Figure 3e. Three-dimensional map of magnetic fields. Basement, Sunnylea P.S.

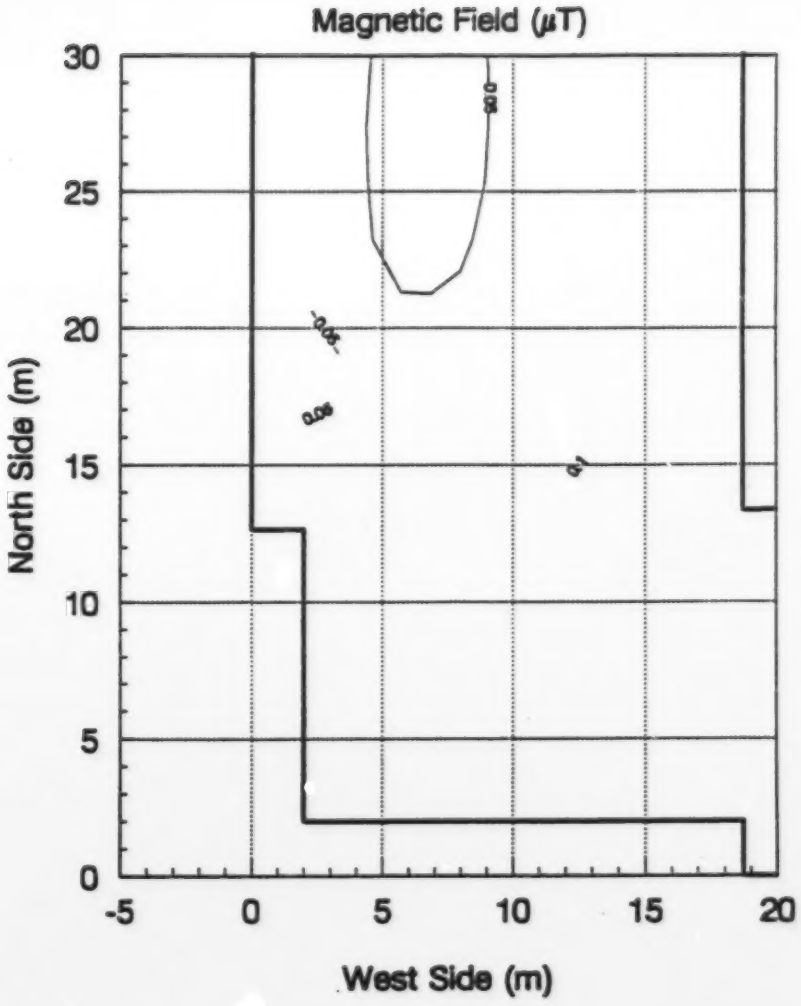

Figure 3f. Contour map of magnetic fields. Basement, Sunnylea P.S.

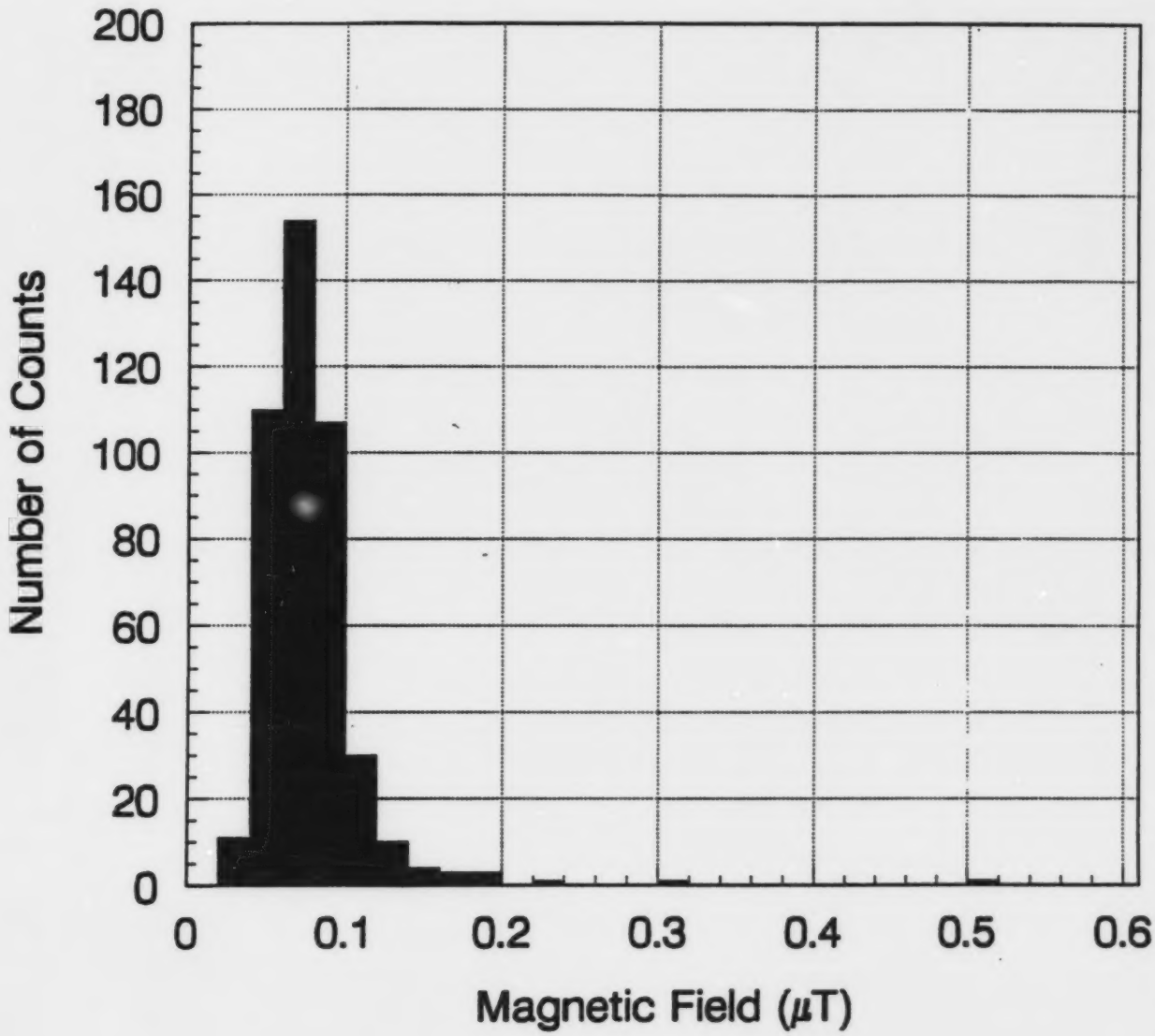

Figure 4a. Histogram of magnetic fields. School building, Sunnylea P.S.

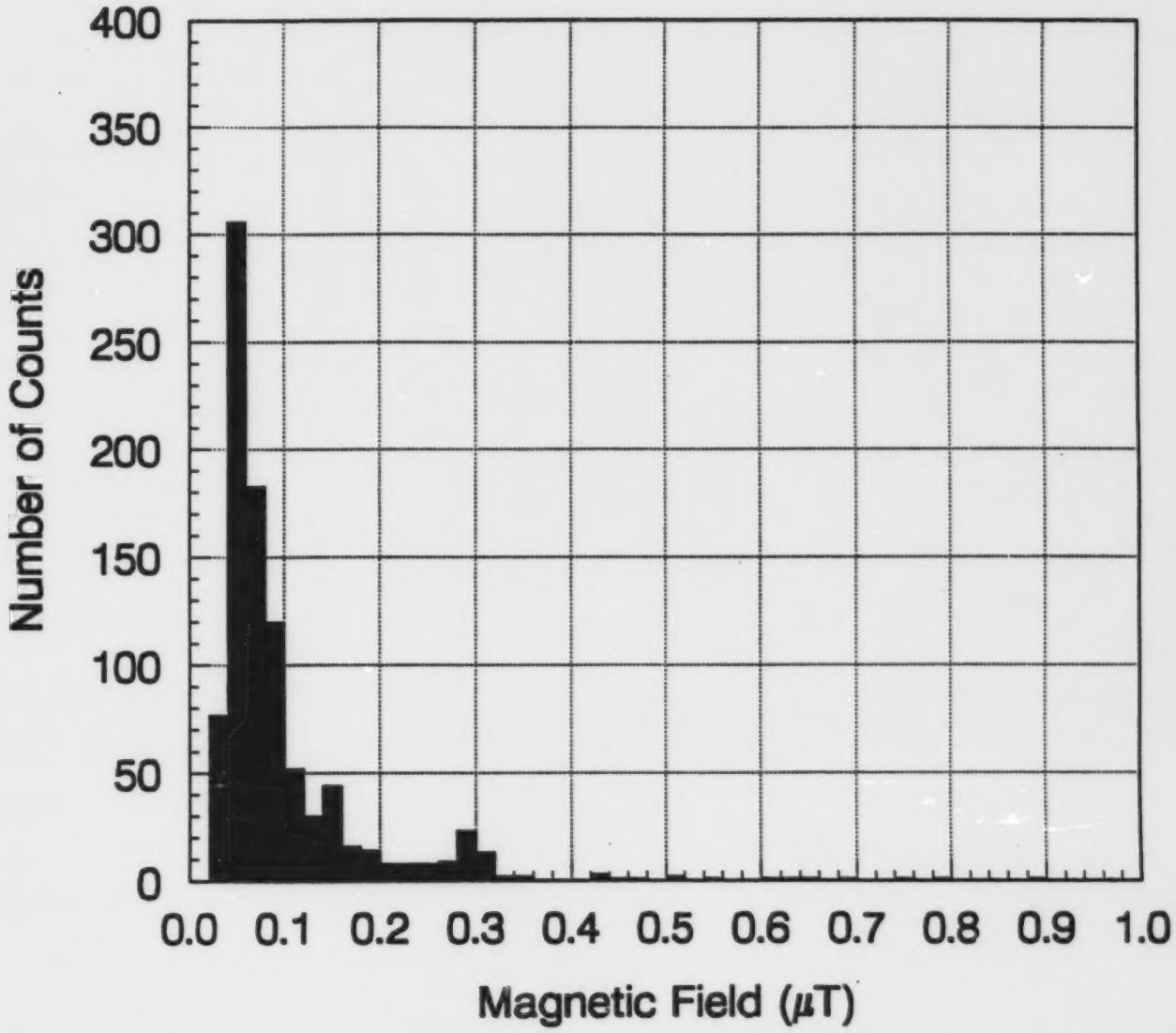

Figure 4b. Histogram of magnetic fields. School building and surrounding school grounds, Sunnylea P.S.

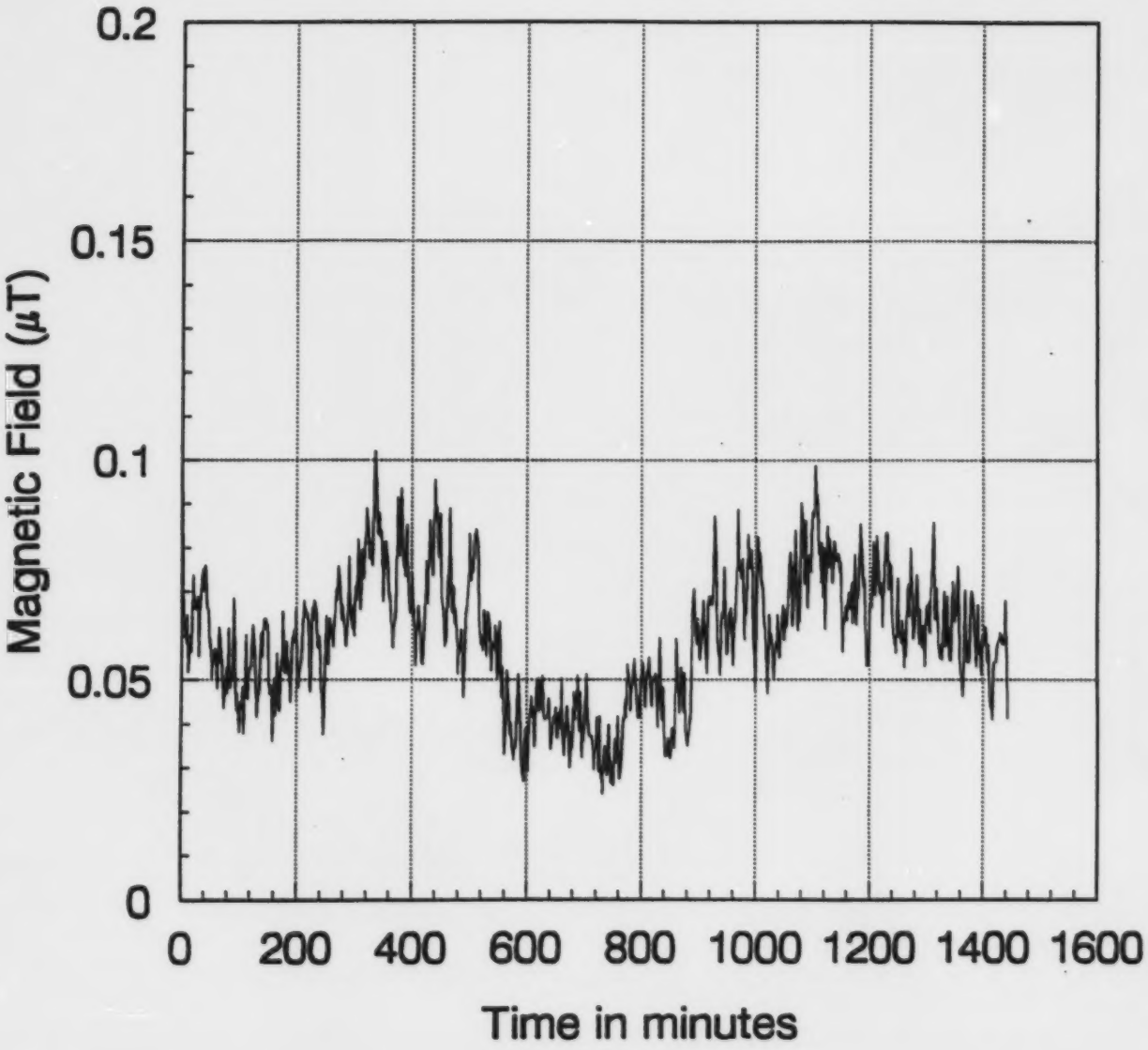

Figure 5. Magnetic field levels over 24-hours. Custodial office, Albion Heights P.S.

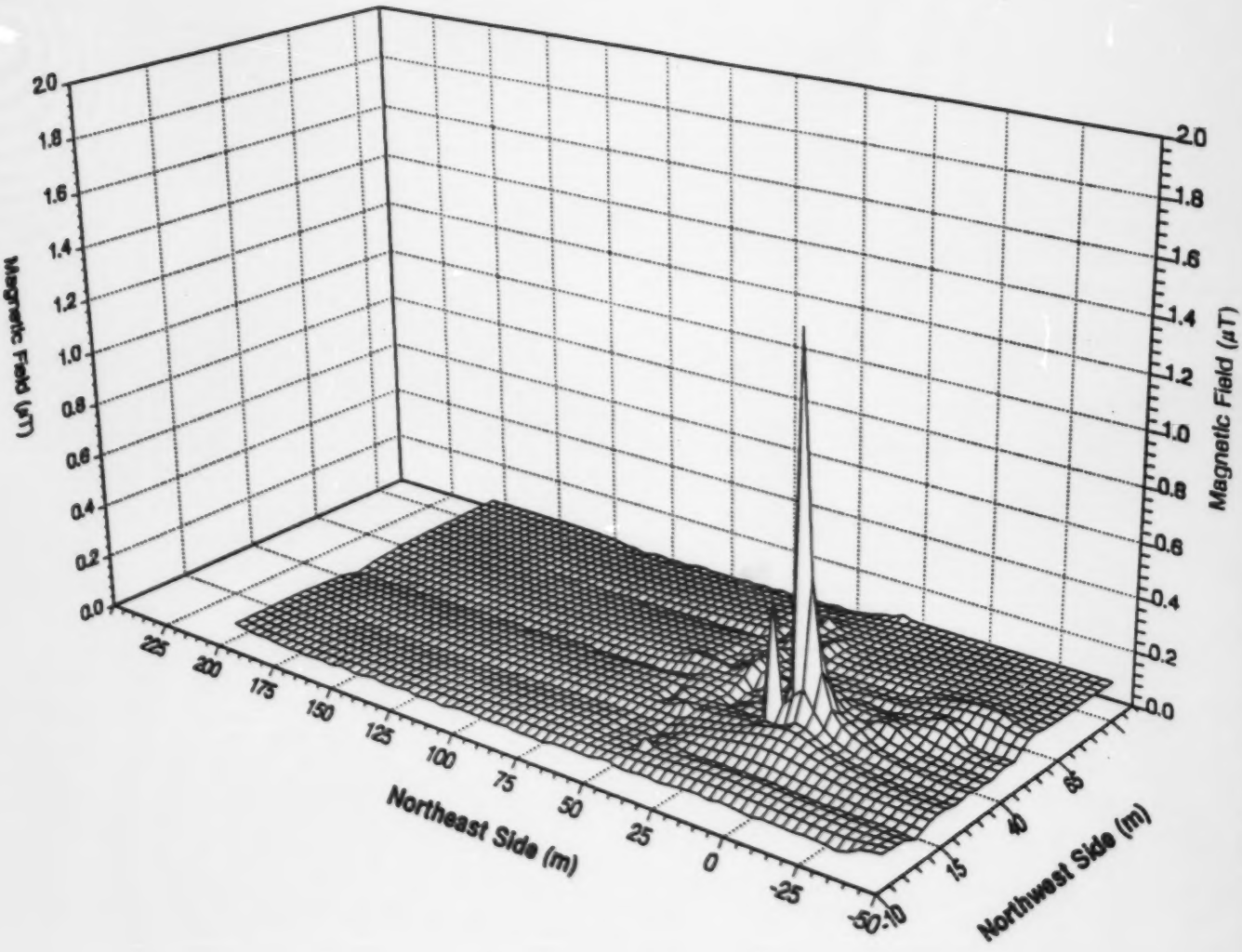

Figure 6a. Three-dimensional map of magnetic fields. First floor and surrounding school grounds, Albion Heights P.S.

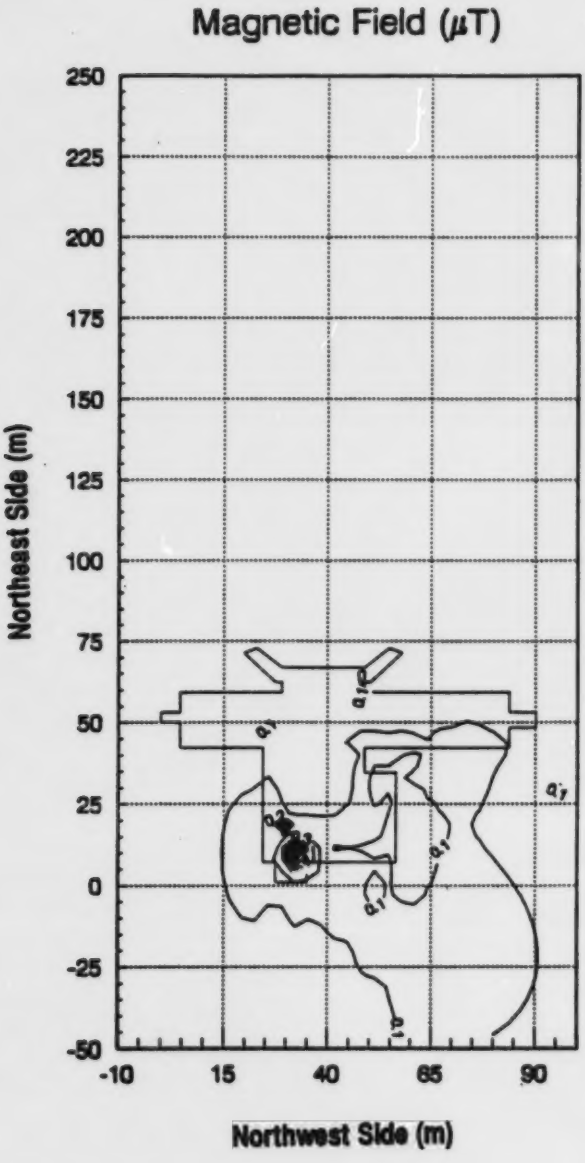

Figure 6b. Contour map of magnetic fields. First floor and surrounding school grounds, Albion Heights P.S.

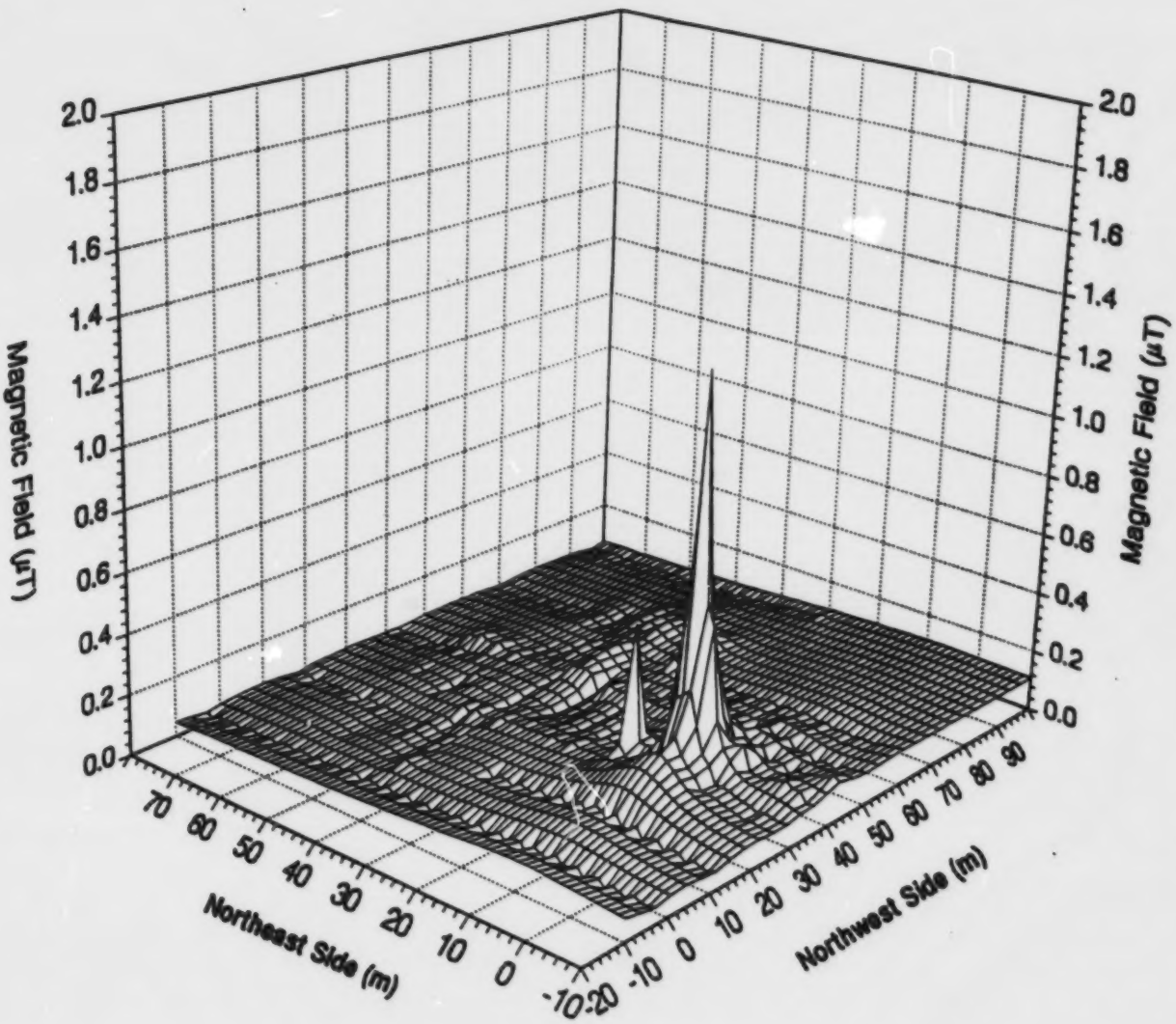

Figure 6c. Three-dimensional map of magnetic fields. First floor, Albion Heights P.S.

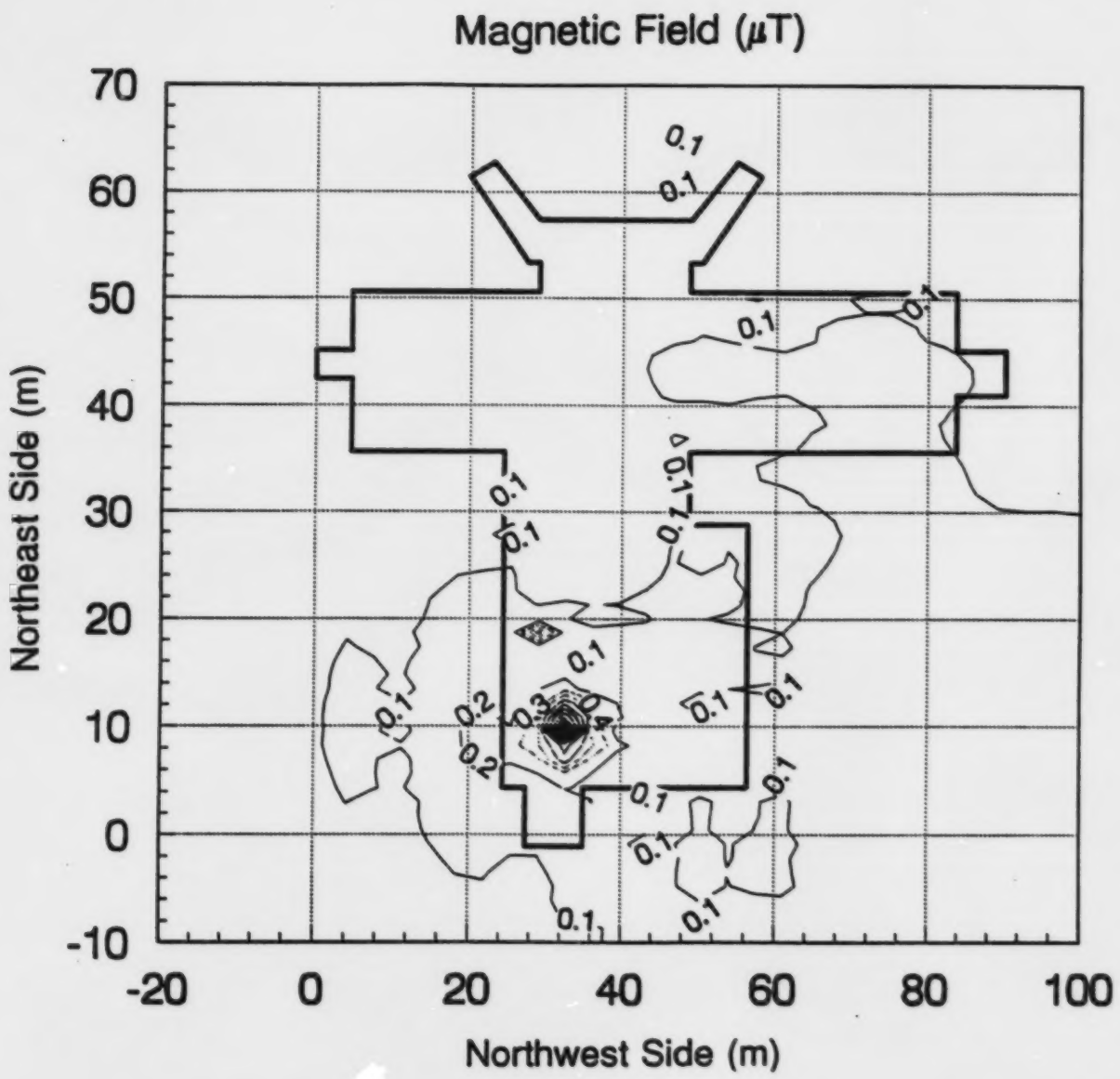

Figure 6d. Contour map of magnetic fields. First floor, Albion Heights.

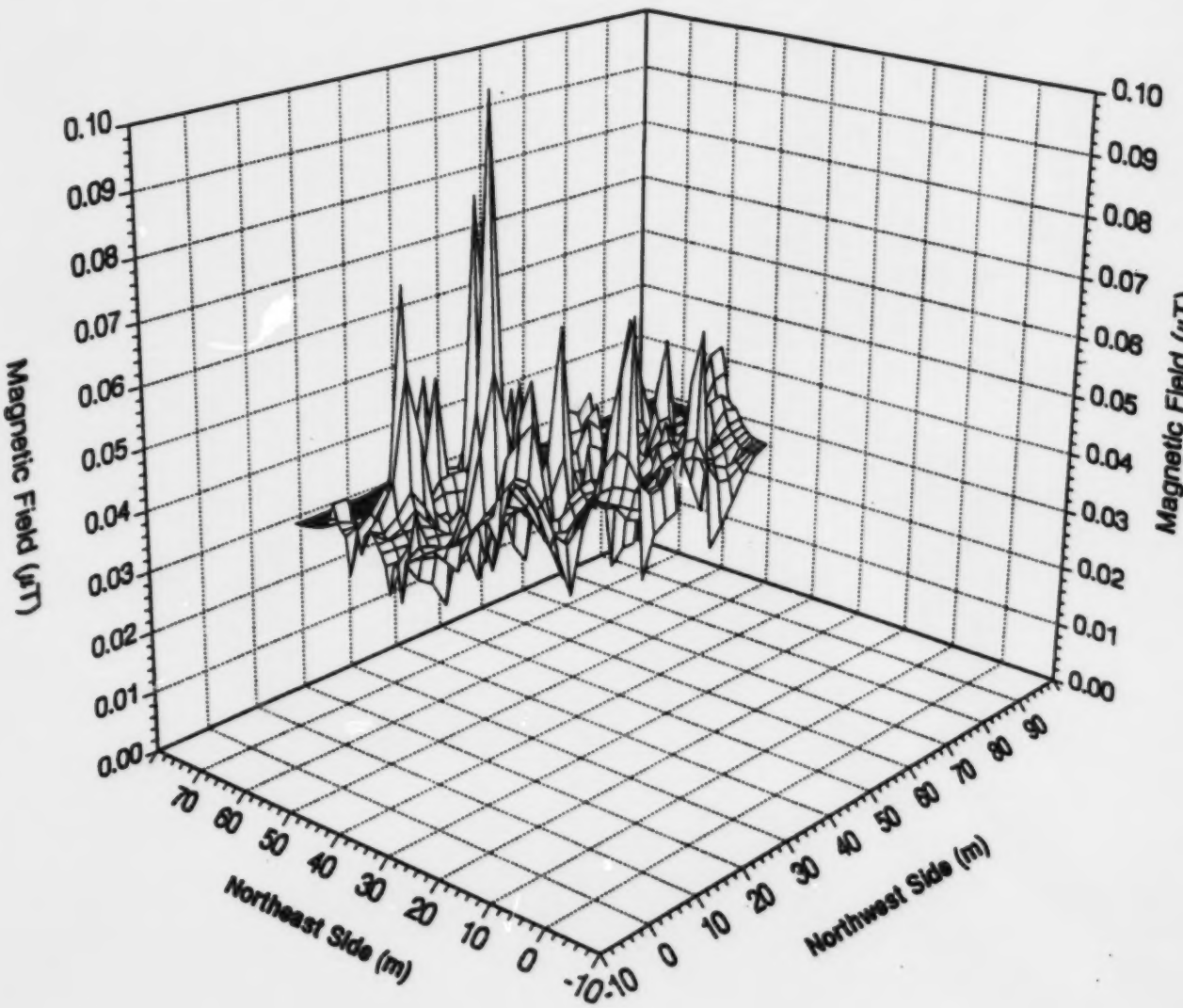

Figure 6e. Three-dimensional map of magnetic fields. Second floor, Albion Heights P.S.

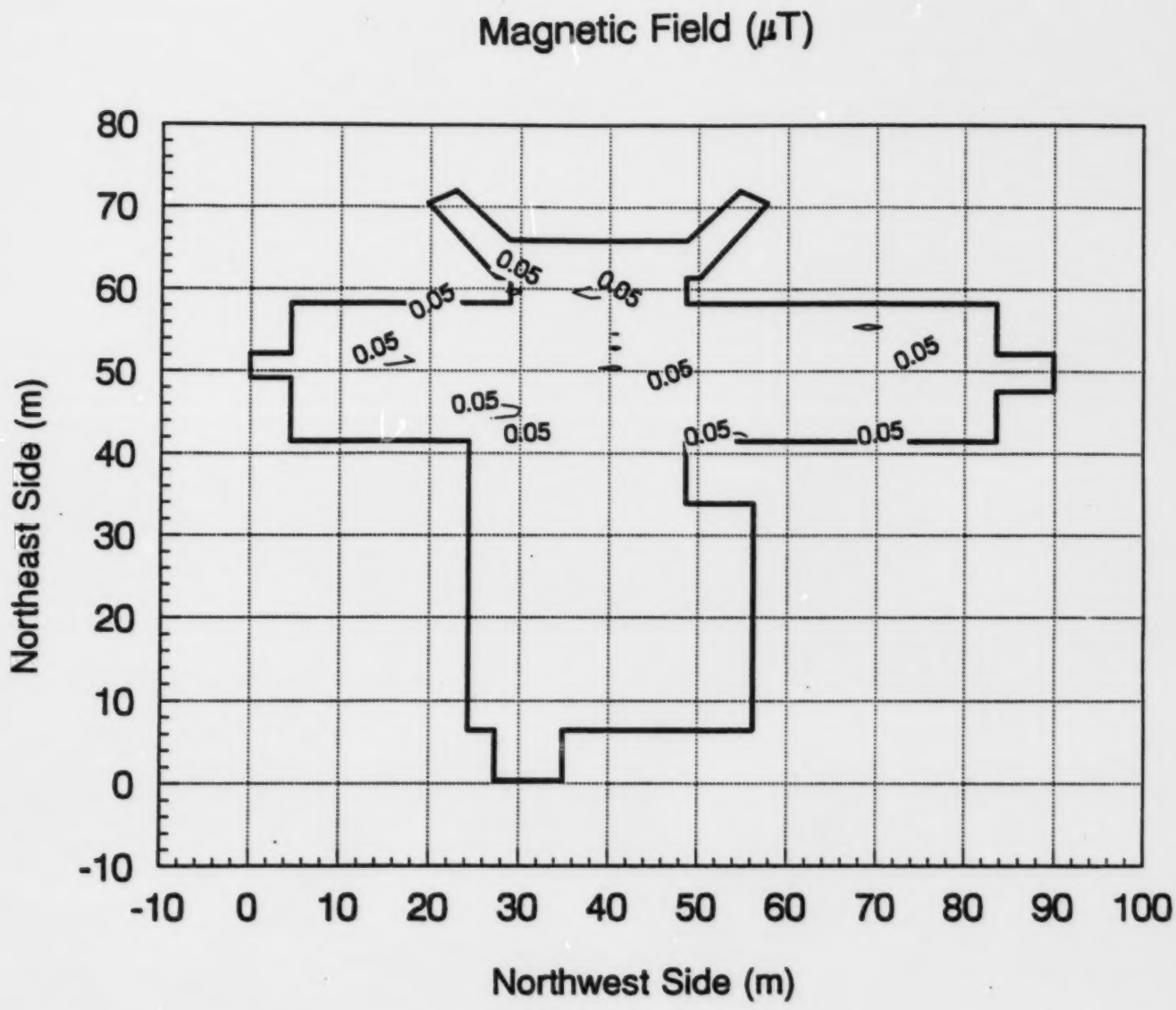

Figure 6f. Contour map of magnetic fields. Second floor, Albion Heights P.S.

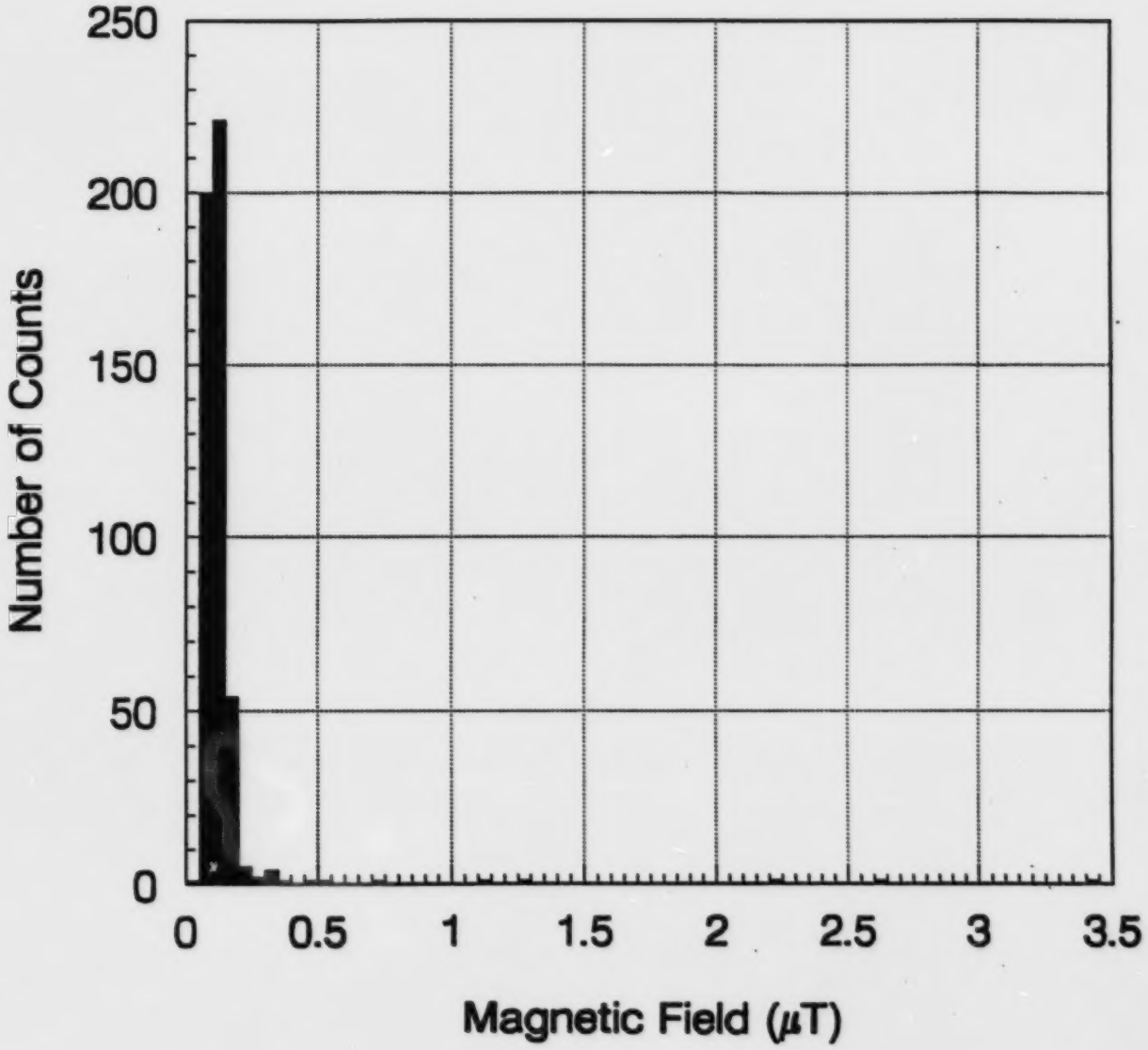

Figure 7a. Histogram of magnetic fields. School building, Albion Heights P.S.

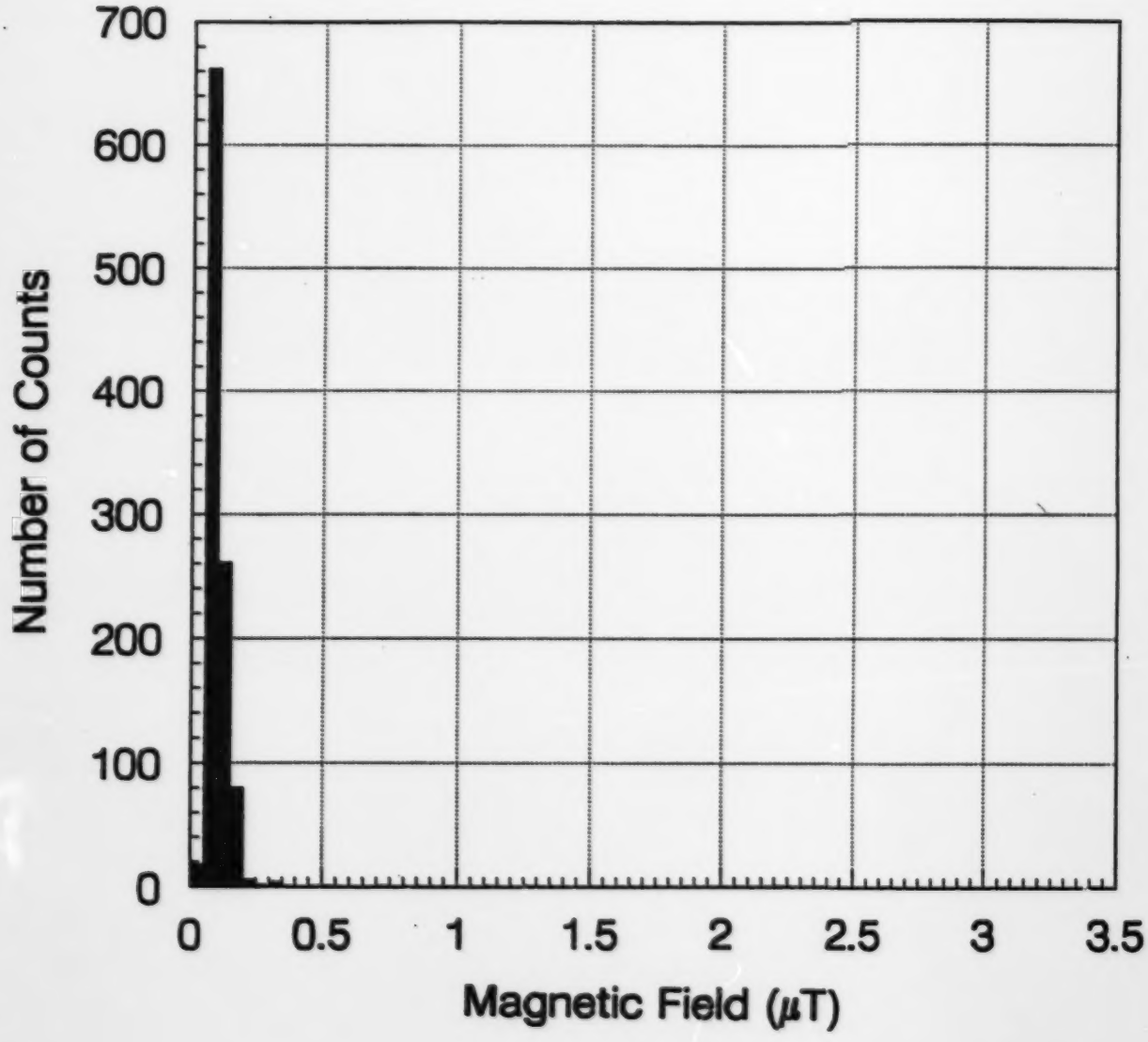

Figure 7b. Histogram of magnetic fields. School building and surrounding school grounds, Albion Heights P.S.

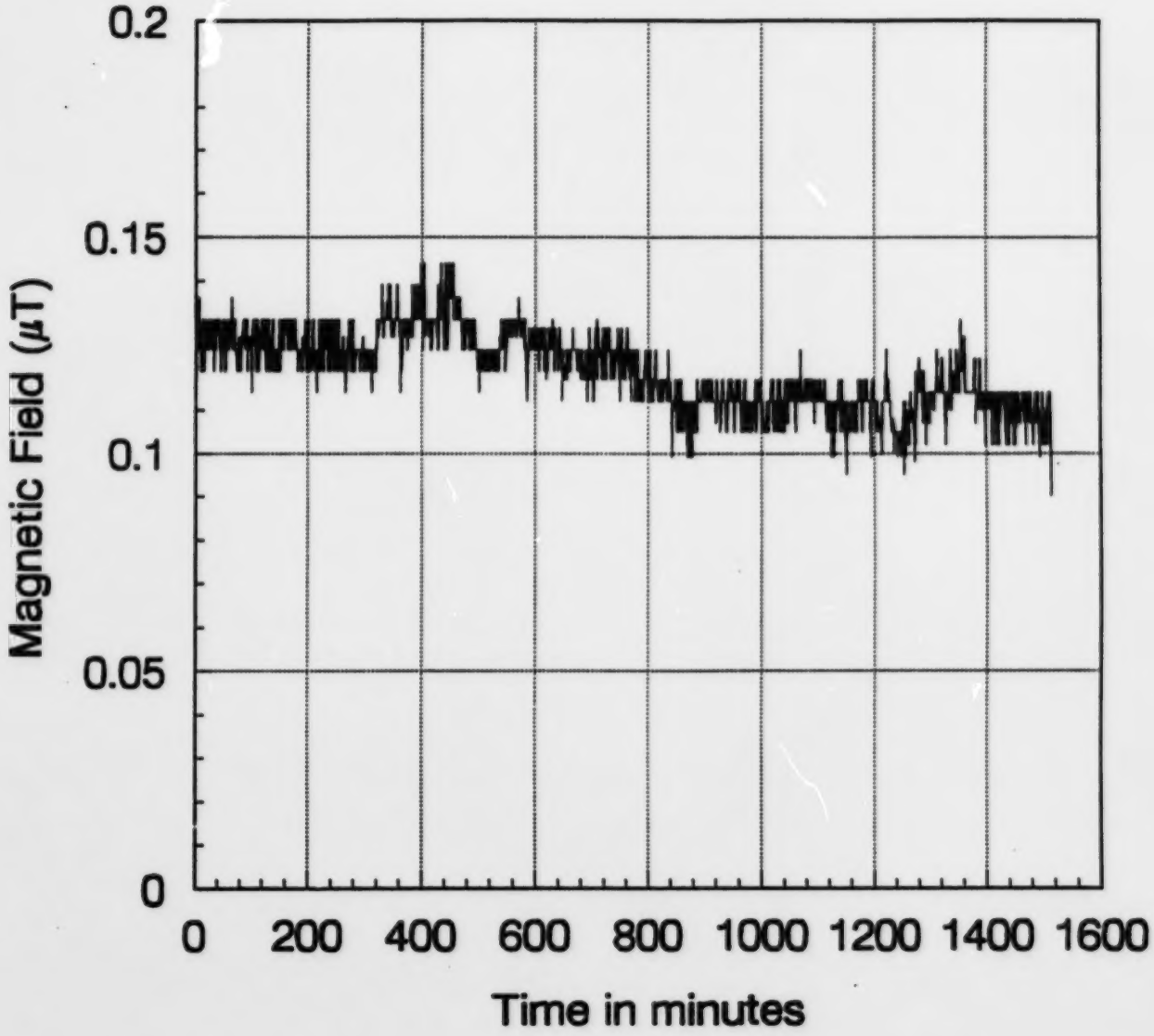

Figure 8. Magnetic field levels over 24-hours. General office, Albion Heights P.S.